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GRAIN SORGHUMS, THEIR PRODUCTS AND USES

Prepared by
W. M. Edwards, Junior Agr. Economist,
and J. J. Curtis, Associate Agr. Technologist
Commodity Development Division
Northern Regional Research Laboratory
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INTRODUCTION

The Northern Regional Research Laboratory at Peoria, Illinois, is one of four large research laboratories established, under authority of the Agricultural Adjustment Act of 1938, by the Bureau of Agricultural Chemistry and Engineering, U. S. Department of Agriculture to conduct researches into and to develop new scientific, chemical, and technical uses and new and extended markets and outlets for farm commodities and the products and byproducts thereof. The commodities originally designated for investigation in the Northern Regional Research Laboratory were wheat, corn, and agricultural residues.

The purpose of this report is to present information concerning grain sorghums in order to show the essential relationship existing between them and wheat and corn. Up to the present time grain sorghums have been an important crop in the United States only in certain semi-arid regions and even there they are not an important cash crop. They are used chiefly for feed on the farms where produced; consequently the quantity entering commercial channels and thence into industrial utilization is small. Research underway and contemplated by the Northern Regional Research Laboratory, Kansas State College, University of Nebraska, and elsewhere may lead to substantial uses for grain sorghums in industry.

The basic information contained herein, showing the properties of grain sorghums, their present and possible uses, and their present position in the over-all agricultural economy, may contribute, it is believed, to the development of new industrial outlets for these grains or in extending their present uses.

The sorghums, although ranking as a relatively minor crop from the standpoint of acreage, production, and trade, in both the United States and the world at large, are nevertheless an important crop in the agricultural economy of certain areas. They are admirably adapted to the semi-arid climatic conditions of the Great Plains area and frequently produce grain and forage when other crops fail.

BOTANICAL DESCRIPTION AND CLASSIFICATION

Sorghums belong to the botanical genus Sorghum of the grass family Gramineae. They are usually tall, robust plants with flat leaf blades and terminal panicles. There are two natural divisions of the genus Sorghum grown as field crops in the United States. The one, Sorghum halepense (Johnson grass), in which the plants are perennial with 20

1/ This report is mainly a compilation of information taken from the selected references given herewith.

chromosomes and creeping rhizomes, is of little importance except for pasture and hay. The other, Sorghum vulgare, in which the plants are annual and have 10 chromosomes, includes all of the cultivated sorghums. These latter are divided agronomically into four general groups: (1) grain sorghums; (2) sorgos (sweet or saccharine sorghums); (3) broomcorn; and (4) grass sorghums.

It is with the sorghums grown and harvested primarily for grain that this report is chiefly concerned. These are principally the so-called grain sorghums, but include also certain members of the sorgo group which give good yields of grain. Moreover, the close relationship existing between all the sorghum groups, and the fact that their differences both as to grain production and juiciness and sweetness of stalk are largely a matter of degree, causes the distinction between and classification of some grain sorghum and sorgo varieties to be difficult and to some extent arbitrary.

For purposes of identification a brief description of the various groups of sorghums follows:

The so-called "grain sorghums" are grown primarily for grain and generally have larger seeds and produce seed more abundantly than the other sorghums. Their stalks have a lower sugar content, and are usually less juicy at maturity than those of the sorgos, although there is a wide range among varieties as regards this factor. Because of its drier stalk and lower sugar content grain sorghum forage is less palatable and nutritious for livestock than sorgo forage. The juiciness of a variety is closely correlated with the color of the leaf midrib. Juicy varieties have a dull gray or cloudy midrib, whereas dry-stalked varieties have a pure white midrib. Stalks of American grain sorghums usually range from 2-1/2 to 6 feet in height.

Some of the leading varieties of grain sorghums are as follows:

Milo varieties: Dwarf Yellow, Double Dwarf Yellow, Beaver, Sooner, Wheatland, Colby, Day, Westland, Caprock, Plainsman.

Kafir varieties: Blackhull, Red, Pink, Dawn, Sunrise, Reed, Club.

Feterita varieties: Standard, Spur, Dwarf.

Durra (Egyptian corn) varieties: White, Brown, Dwarf. (None of these any longer commercially important except in California).

Miscellaneous varieties: Dwarf hegari, Darso, Schrock, Early kalo, Shallu, Altamont kaoliang, Bonita, Ajax, Grohoma, Freed, etc.

The sorgos, or sweet-stemmed sorghums, are grown primarily for forage and to a lesser extent for sirup and for grain. The varieties differ considerably in height, date of maturity, and head and kernel characters; the stalks usually range from 5 to 10 feet in height and the seeds are small to medium in size and are either white or various shades of brown in color. Some of the leading varieties of sorgos are: Black Amber, Kansas Orange, Sumac, Honey, Red Amber, Atlas, Norkan and Leoti.

In some parts of the United States, sorgo, or sweet sorghum, is often erroneously called sugarcane, sometimes with the prefix "seeded" to indicate that it is propagated by seeds instead of cuttings, as is the case with true sugarcane. The latter belongs to an altogether different botanical genus (Saccharum) of the grass family Gramineae. The sugarcane seed is quite different in appearance from either sorgo or grain sorghum seeds. Mature sugarcane seed is seldom produced by cultivated plants.

Broomcorn produces heads with fibrous seed branches 12 to 36 inches long, which are used for making brooms. The stalks range from 3 to 14 feet in height and are dry, not sweet, and of limited value for forage. Some of the leading broomcorn varieties are: Evergreen, Black Spanish, and Scarborough.

The annual grass sorghums have narrow leaves and slender stalks and are grown principally for hay and pasture. Included among these are: Sudan grass, Tunis grass, Tabucki grass, Toura grass, and Kamerun grass. Of these only Sudan grass is grown commercially in the United States.

The perennial sorghum, Johnson Grass, is similar to Sudan grass except that it is perennial and has underground stems. It is very prolific and on fertile ground may become a noxious weed because of the difficulty of its eradication. It crosses occasionally with Sudan grass and other sorghums but since it has 20 instead of the usual 10 pairs of chromosomes, only part of the crosses are fertile.

ORIGIN

Plant scientists generally believe that sorghums are native to Africa and India. Since these regions are thought also to have cradled the human race, it is reasonable to believe that sorghums were among the earliest of the wild plants to be domesticated and utilized as human food and livestock feed.

The oldest discovered evidence of their utilization is a carving on the palace walls of King Sennacherib in Nineveh, Assyria. The design dates from about 700 B. C. and shows a field of mature grain sorghum in which several hogs are grazing. There are records also of the presence of sorghum in India in the first century A. D. and in China in the thirteenth century. And today millions of Africans and Asiatics, who cannot afford wheat or rice, consume grain sorghums for food in the form of bread and porridge. An alcoholic drink resembling beer and a confection are also

made from the grain. The stalks in some instances have served as a substitute for wood fuel, and have been used for making baskets, furniture, mats, shelter, fences, and toys.

Production Development in the United States

The first sorghums introduced into this country arrived on slave ships from Africa, during colonial times. None of these, however, became permanently established in our agricultural economy. The continuous culture of sorghums began in the United States in 1853 with the sorgos.

In that year the sorgo, Chinese Amber, which had been sent to France from the island of Tsungming in China, was introduced into the United States. Later, in 1857 Leonard Wray, an English sugar planter in Natal, South Africa, brought 16 additional varieties of sorgo to America and grew them in Georgia and South Carolina. All subsequent American sorgos have been developed from these 16 varieties and Chinese Amber, except the varieties Collier, Planter, and McLean sorgo which were introduced between 1881 and 1891 by the Department of Agriculture.

The grain sorghums, White durra and Brown durra, were introduced from Egypt to California in 1874, and their success was the beginning of our continued and expanding grain sorghums culture. White kafir, Red kafir, Milo, Shallu, Pink kafir, Feterita, and Hegari were later introduced and these, plus the 20 previously mentioned sorgo varieties, were the progenitors of the more than 80 distinct varieties of grain sorghums and sorgos now grown commercially in the United States.

STRUCTURE AND COMPOSITION OF KERNEL

Basically the sorghum kernel resembles other cereal grains in both structure, (see figure 1) and composition. Structurally it consists of three parts: the pericarp or seed coat, the endosperm, and the embryo or germ. Although differing according to variety, the pericarp of a typical grain variety constitutes about 6 percent by weight of the average kernel, the endosperm about 84 percent, and the germ about 10 percent.

The pericarp is responsible for the seed color and is composed of several differentiated layers of cells. (See figure 2.) The pigmentation or color is carried in two distinct layers, (1) the epicarp, or outer layer, and (2) the nucellar layer[2/], which lies next to the aleurone layer of the endosperm. The nucellar layer is absent in some varieties, but when present is reddish brown in color. Between the epicarp and the nucellar layer is a starchy layer of cells called the mesocarp. This layer may be either thick or thin. If thick, it obscures the color of the nucellar layer. If the mesocarp is vestigial in development, the pigment in the

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2/ Considered by Ayyangar and Krishnaswami to be inner integument.

nucellar cells is visible in varying degrees of intensity through the pericarp. The epicarp may or may not form a pigment according to the variety. When no color occurs in the epicarp simultaneously with an absent or obscured nucellar layer, a white-colored seed results. The many combinations of factors which influence color in the sorghum kernel may, therefore, result in numerous colors. The colors listed in the descriptions of sorghum kernels are white, chalky white, pink, yellow, red, buff or brownish-yellow, brown, and reddish-brown. Some white-seeded varieties also have pink, red, brown, or black spots.

The endosperm comprises the bulk of the kernel and, therefore, its properties and characteristics in large measure determine the utility and value of the kernel. It consists mainly of starch which may be of sugary, waxy, or non-waxy (common) character.

Varieties having sugary endosperm are a rarity, but have been bred and produced in this country by crossing adapted American varieties with a foreign sugary strain. Waxy starch-bearing sorghums, although not new in the United States, have received very little attention until recently. They now give promise of becoming important because of the unusual properties of their starch. The non-waxy starch varieties are the most common and their starch resembles that of other cereal grains. The endosperm of non-waxy kernels consists of an outer corneous portion and an inner chalky or soft-starchy portion. The endosperm of waxy kernels, although waxy throughout, is also divided into hard outer and softer inner portions. The relative amount of the corneous portion in the kernel of all sorghums is to some extent a varietal characteristic, although it is considerably influenced by environment.

The germ of a typical grain sorghum contains approximately 70 percent of the fat and 13 percent of the protein present in the entire kernel.

The size of sorghum kernels varies widely, the sorgos generally producing smaller seeds than the grain sorghums. Figure 3 shows the shape and markings of various varieties. In general, the small seeds weigh about 8 to 11 grams per thousand, medium-sized seeds weigh from 12 to 24 grams per thousand, and large seeds usually weigh from 25 to 35 grams per thousand. Occasional lots of large-seeded feterita or milo weigh over 40 grams per thousand seeds.

Table 1 shows the average chemical composition, weight per 1000 kernels, and weight per bushel of seven varieties of grain sorghums as compared with dent corn. It is apparent from these data that grain sorghums contain more protein, but are lower in both fiber and fat content than corn. In table 2 is shown the proportion of the kernel and chemical composition of the bran, endosperm, and germ portions of the kernels of three grain sorghum varieties. Table 3 presents additional chemical composition data for 9 sorghums. Results of physical and chemical determinations made by the Northern Regional Research Laboratory on 26 samples of sorghum seed, representing 21 varieties, are shown in tables 4 and 5.

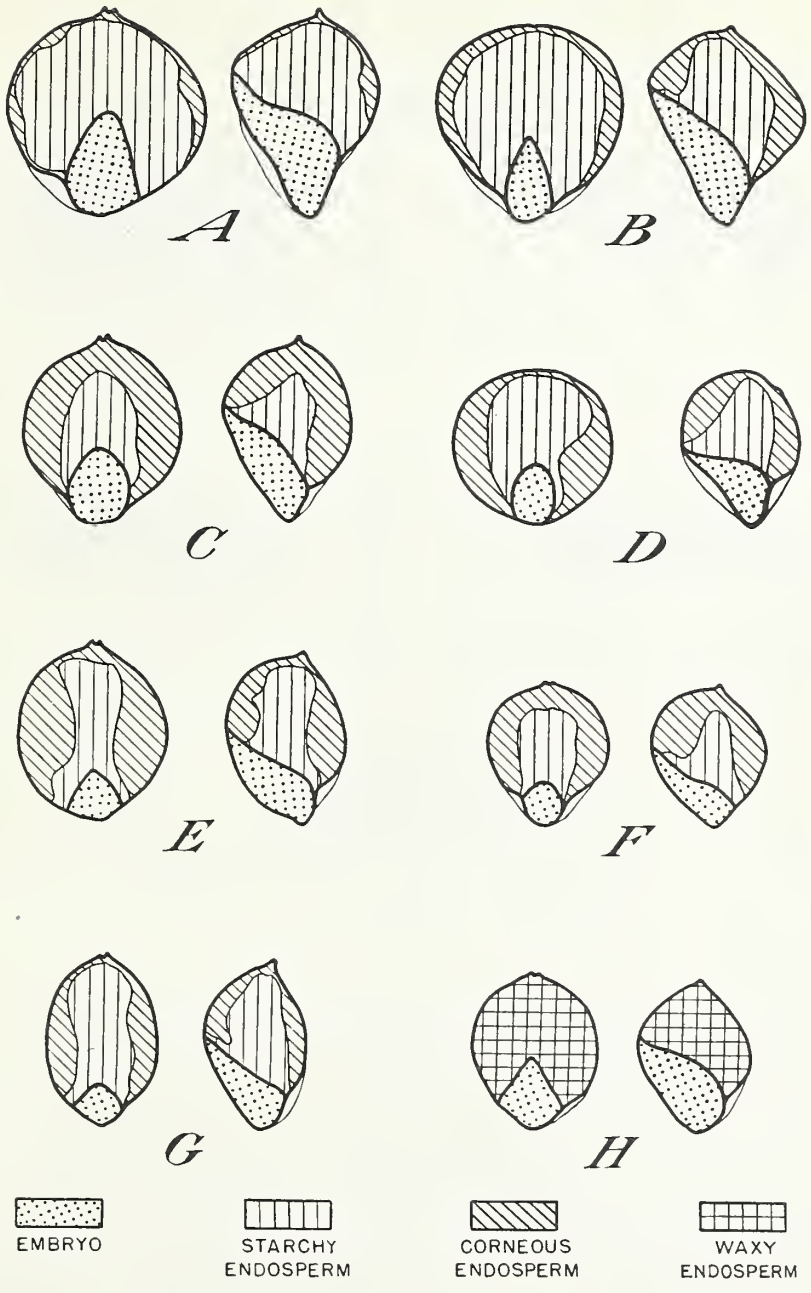

Figure 1. - Outline drawings of dorsoventral and lateral cross sections of sorghum seed, showing variations in (1) size and shape, (2) proportion of outer corneous and inner soft starch in endosperm, and (3) size and shape of embryo: A, Standard feterita; B, Standard Yellow milo; C, Blackhull kafir; D, hegari; E, Orange sorgo; F, Sumac sorgo; G, Sapling sorgo; H, Gooseneck sorgo (endosperm waxy).

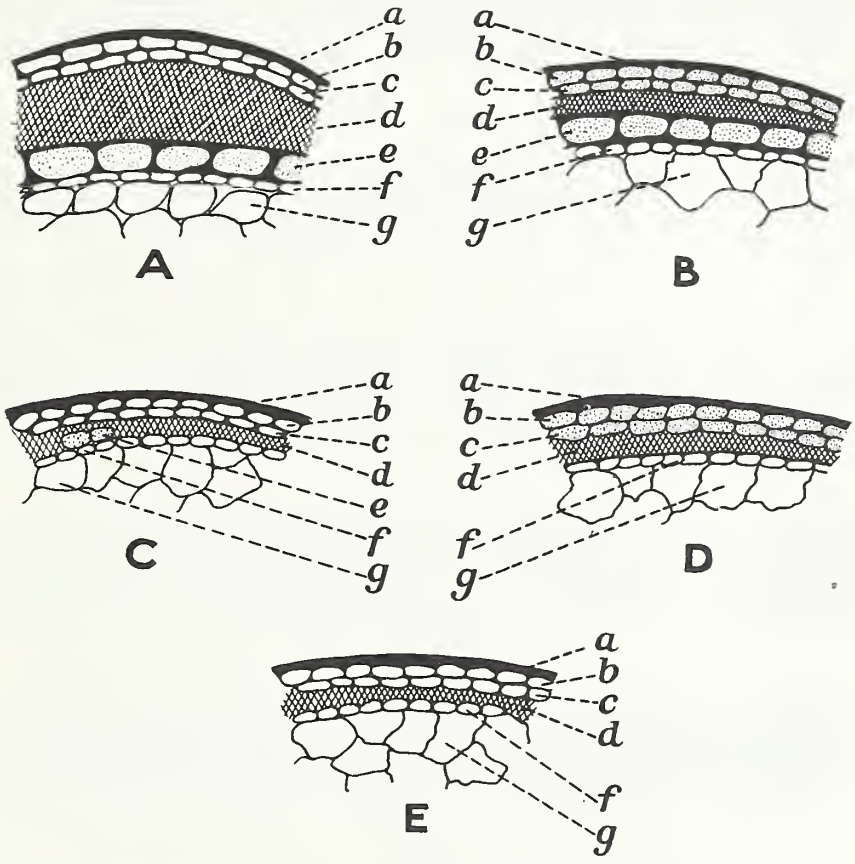

Figure 2. - Diagrammatic sections of the seed coats of five sorghum varieties: a, Cuticle; b, epidermis; c, hypoderm; d, mesocarp; e, nucellar layer; f, aleurone layer; g, endosperm. A, Feterita; colorless epidermis and hypoderm, highly developed mesocarp, and nucellar layer; B, Red Amber; colored epidermis and hypoderm, thin mesocarp, nucellar layer; C, Blackhull kafir; colorless epidermis and hypoderm, thin mesocarp, and nucellar layer absent except for slight remnants; D, Yellow milo; colored epidermis and hypoderm, thin mesocarp, nucellar layer absent; E, Freed sorgo and White milo; colorless epidermis and hypoderm, thin mesocarp, nucellar layer absent

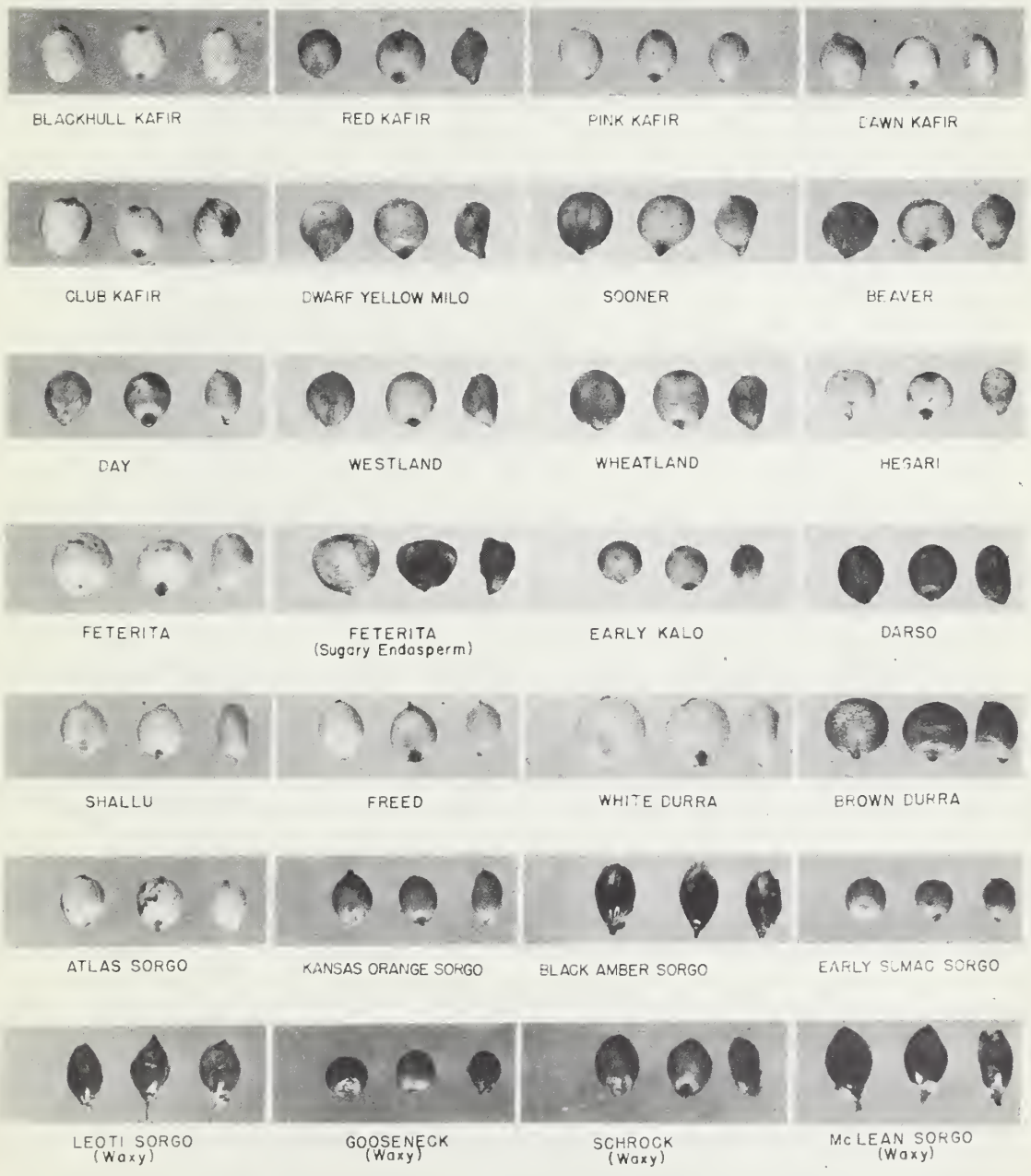

FIGURE 3. – SHAPE AND RELATIVE SIZES OF THE SEED OF 28 VARIETIES OF SORGHUM. (X 2)

Chemical analytical data pertaining to the hulls removed, by hand, from a sample of Leoti sorghum are as follows:

Determination	Moisture-free basis Percent
Ash	7.66
SiO_2	6.59
Hot water soluble	9.6
1% alkali soluble	50.1
Alcohol-benzene soluble	12.1
Benzene extract	1.1
95% alcohol extract	11.3
Nitrogen	.58
Crude lignin	16.6
Nitrogen in crude lignin	1.14
Methoxyl in crude lignin	8.5
Ash-free lignin	12.8
Pentosans	32.8
Cross & Bevan cellulose, crude	56.0

Table 1 - Average chemical composition, weight per 1000 kernels, and weight per bushel of seven grain sorghum varieties 1/, compared with dent corn.

Variety	No. of analyses	Moisture-free basis					Weight per -	
		Ash	Protein	Carbohydrates	Fat	Fiber	1000 kernels	Bushel
		Percent	Percent	Percent	Percent	Percent	Grams	Pounds
Milo	67	1.79	13.83	79.28	3.47	1.63	36.1	58.1
Dwarf milo	55	1.80	13.42	79.55	3.61	1.62	31.4	58.2
Feterita	8	1.90	15.48	77.77	3.21	1.64	32.2	55.9
Blackhull kafir	78	1.97	15.59	76.85	3.84	1.75	21.6	58.0
Dwarf blackhull kafir	13	1.89	14.53	78.28	3.61	1.69	16.6	58.7
Red kafir	37	1.91	13.28	79.64	3.50	1.67	18.5	58.3
Shallu	10	2.21	16.93	74.60	4.12	2.14	15.1	57.9
Average of all varieties	268	1.88	14.38	78.41	3.64	1.69	26.6	58.1
Dent corn	86	1.68	11.52	78.75	5.59	2.46	2/316.7	2/ 59.6

1/ Samples grown at the Amarillo Cereal Field Station for the five years 1908-1912, except the Shallu samples which were grown only in 1911 and 1912.

2/ Corn weights compiled and computed on 86 samples of dent corn from records of Northern Regional Research Laboratory.

Source: Uses of sorghum grain. By C. R. Ball and B. E. Rothgeb, U. S. Dept. Agr. Farmers Bul. 686, 1915.

Table 2 - Proportions of component parts of whole grain or kernel and chemical composition of the whole kernel and its parts, for three grain sorghum varieties. (Moisture-free basis).

Variety and component part of kernel	Proportion of kernel	Ash	Ether extract	Protein	Crude fiber	Nitrogen free extract	Starch
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Dawn kafir:							
Whole grain	100.0	1.80	4.10	12.70	1.80	79.60	61.90
Bran	6.1	2.00	6.80	4.80	16.20	70.20	--
Corneous endosperm	48.9	.30	.70	14.50	.70	83.80	68.80
Starchy endosperm	35.0	.30	.80	11.66	.80	86.44	70.40
Germ	10.0	13.20	31.50	19.30	3.80	32.20	--
Dwarf milo:							
Whole grain	100.0	1.89	3.47	13.99	1.93	78.72	68.52
Bran	5.5	3.07	4.33	7.08	15.36	70.16	1.60
Corneous endosperm	54.7	.56	.15	15.11	.69	83.49	72.24
Starchy endosperm	28.7	.71	.28	8.91	.81	89.29	82.50
Germ	11.1	9.46	19.92	20.84	9.11	40.67	1.53
Feterita:							
Whole grain	100.0	1.79	3.06	16.69	2.22	76.24	64.16
Bran	6.6	2.95	5.74	6.85	13.56	70.90	3.89
Corneous endosperm	61.0	.71	.33	19.75	2.12	77.09	60.36
Starchy endosperm	25.1	.96	.64	10.61	2.38	85.41	75.84
Germ	7.3	11.35	25.45	21.70	8.54	32.96	2.16

Source: A physical and chemical study of milo and feterita kernels. By G. L. Bidwell, et al. U. S. Dept. Agr. Bul. 1129, 1922.

Table 3 - Chemical composition of the grain of 9 sorghums.

(Moisture-free basis)

Class	Crude protein	Ash	Ether extract	Crude fiber	Nitrogen-free extract
	Percent	Percent	Percent	Percent	Percent
White kafir	10.08	1.44	4.04	2.05	82.39
Red kafir	11.25	1.43	5.40	1.81	80.11
Yellow milo	12.98	1.34	4.77	1.94	78.97
Brown Kaoliang	15.73	1.84	6.10	1.71	74.62
Darso	9.33	1.27	4.19	1.71	83.50
Feterita	14.52	1.28	5.10	2.04	77.06
Freed sorgo	14.47	1.78	5.06	1.65	77.04
Shallu	10.28	1.40	4.54	2.29	81.49
Schrock	9.72	1.33	5.92	2.26	80.77

Source: Respiration of sorghum grains. By D. A. Coleman, et al. U. S. Dept. Agr. Tech. Bul. 100.

Table 4 - Grade and physical characteristics of the grain of 26 varieties of sorghum
(See Table 5 for chemical analyses)

C.D. sample No.	Variety	Source	Crop year	Grade 1/	Weight per bushel 2/	Damaged kernels 2/	Total cracked kernels, etc. 2/ 3/	Weight per 1,000 kernels	Glumes attached to kernels 4/ Proportion by number	Glumes attached to kernels 4/ Proportion by weight
					Pounds	Percent	Percent	Grams	Percent	Percent
1625	Pink kafir	Hays, Kans.	1940	#1 Brt. white kafir	59.5	0.0	0.0	18.6	0.0	0.0
1626	Pink kafir	Hays, Kans.	1941	#1 White kafir	59.1	.3	.0	22.3	.9	.1
2369	Pink kafir	Hays, Kans.	1942	#1 White kafir	57.5	1.4	.0	18.2	2.7	.2
2372	Red kafir	Hays, Kans.	1942	#2 Red kafir	53.5	1.3	.0	16.3	1.5	.2
1922	Texas Blackhull kafir	Lubbock, Tex.	1941	#1 White kafir, Disc.	58.7	1.0	.0	29.0	.1	5/
2368	Western Blackhull kafir	Hays, Kans.	1942	#2 White kafir	55.7	4.6	.0	21.9	2.4	.3
2370	Club kafir	Hays, Kans.	1942	#2 White kafir	54.2	2.4	.0	29.5	5.0	.5
2371	Dawn kafir	Hays, Kans.	1942	#2 White kafir	53.3	1.3	.0	18.8	9.1	1.1
1925	Yellow milo	Lubbock, Tex.	1941	#1 Yellow milo	55.9	.7	1.3	30.2	2.5	.3
2373	Wheatland	Hays, Kans.	1942	#1 Yellow milo	59.4	.7	.0	29.3	1.8	.2
2374	Sooner	Hays, Kans.	1942	#1 Yellow milo	57.1	1.2	.0	32.8	5.4	.6
2375	Westland	Hays, Kans.	1942	#2 Yellow milo	54.3	.9	.0	21.0	4.6	.6
2376	Beaver	Hays, Kans.	1942	#2 Yellow milo	53.3	.5	.0	24.7	3.0	.4
2377	Finney milo	Hays, Kans.	1942	#1 Yellow milo	58.4	1.9	.0	34.4	.9	.1
2365	Hegari	Hays, Kans.	1942	#3 White kafir, Disc.	52.1	7.5	.0	19.8	10.5	.6
2367	Early kalo	Hays, Kans.	1942	#1 Yellow milo	58.7	.7	.0	18.7	.5	.1
2366	Early Sumac sorgo	Hays, Kans.	1942	Non-grain sorghum	55.8	.0	.0	14.5	6.5	.2
2362	Atlas sorgo	Hays, Kans.	1942	#2 White kafir	58.3	3.7	.1	20.9	3.8	.3
2363	Kansas Orange sorgo	Hays, Kans.	1942	Non-grain sorghum	55.8	.1	.1	18.1	19.2	.7
2361	Black Amber	Hays, Kans.	1942	Non-grain sorghum	50.4	.5	.0	20.4	92.0	15.0
2378	Red African	Hays, Kans.	1942	#1 Red kafir	57.1	1.2	.0	22.2	6.8	.6
2379	Klerksdrop No. 2	Hays, Kans.	1942	#2 Red kafir	59.1	3.2	.0	26.0	.3	5/
2380	Kliskama	Hays, Kans.	1942	#1 (Unclassified)	57.1	.1	.0	21.6	1.5	.2
1928	Leoti sorgo (waxy)	Lincoln, Nebr.	1941	Non-grain sorghum	52.0	.0	.0	20.5	51.0	10.8
2364	Leoti sorgo (waxy)	Hays, Kans.	1942	Non-grain sorghum	49.5	.2	.0	21.5	65.5	4.7
1921	Sugary Feterita S.A. 5062-3-2	Lubbock, Tex.	1941	Non-grain sorghum	48.3	2.5	.1	26.0	3.5	.6

1/ None of the samples analysed contained more than 0.05 percent of Dockage. Abbreviations used: Brt. = Bright; Disc. = Discolored. 2/ Determinations made in accordance with Official Grain Standards of the United States. 3/ Total cracked kernels, foreign material, and other grains. 4/ Basis 1000 whole kernels. 5/ Less than 0.05 percent.

Determinations by Commodity Development Division, Northern Regional Research Laboratory.

Table 5. - Chemical composition (moisture-free basis)[1/] of the grain of specified varieties of sorghums and of a composite sample of the glumes removed therefrom (See table 4 for physical data relative to these samples).

C.D. sample No.	Variety	Ash	Oil	Protein (N. x 6.25)	Sugar	Pentosans	Starch: Polarimetric method	Starch: Diastase method
		Percent	Percent	Percent	Percent	Percent	Percent	Percent
1625	Pink kafir	1.68	4.09	12.94	1.22	2.57	68.4	68.7
1626	Pink kafir	1.85	4.12	12.44	1.25	2.33	71.0	69.4
2369	Pink kafir	1.83	4.12	13.44	1.38	2.40	69.0	65.5
2372	Red kafir	2.01	3.49	12.25	.98	2.46	69.1	67.5
1922	Texas Blackhull kafir	1.73	3.60	12.50	1.00	2.24	71.7	69.2
2368	Western Blackhull kafir	1.92	3.79	14.12	1.14	2.55	69.0	68.8
2370	Club kafir	1.90	2.90	13.44	.86	1.96	71.9	70.0
2371	Dawn kafir	1.99	3.68	13.06	1.12	2.35	71.5	66.9
1925	Yellow milo	1.62	3.27	11.56	.94	2.19	72.6	70.9
2373	Wheatland	1.78	3.80	13.06	1.42	2.26	70.6	68.7
2374	Sooner	1.97	3.46	14.19	1.40	2.05	69.7	67.0
2375	Westland	2.29	3.29	15.00	1.19	2.61	67.5	65.8
2376	Beaver	2.23	3.10	15.38	1.10	2.64	68.0	64.7
2377	Finney milo	1.87	3.72	14.44	1.49	2.17	69.4	67.4
2365	Hegari	1.78	2.99	11.56	.81	1.78	72.3	70.6
2367	Early kalo	1.80	3.23	11.88	1.13	2.23	71.8	70.8
2366	Early Sumac sorgo	1.85	3.72	12.19	1.30	2.04	68.8	67.2
2362	Atlas sorgo	1.74	4.14	13.38	1.33	2.35	71.0	69.2
2363	Kansas Orange sorgo	1.81	4.14	13.06	1.34	1.99	67.3	65.3
2361	Black Amber	1.98	4.86	16.56	1.33	1.92	65.1	64.5
2378	Red African	1.72	3.42	13.19	1.50	2.03	68.6	69.1
2379	Klerksdrop No. 2	1.88	3.47	13.88	1.21	2.25	70.2	69.0
2380	Kliskama	1.90	3.37	12.75	1.59	2.38	68.2	67.4
1928	Leoti sorgo (waxy)	1.66	4.13	12.75	.90	2.09	67.8	66.5
2364	Leoti sorgo(waxy)	1.84	4.51	13.25	.99	1.92	67.9	68.0
1921	Sugary Feterita S.A. 5062-3-2	1.95	4.93	12.69	1.30	2.36	63.4	63.9
2729	Glumes (hulls) 2/	10.14	.43	4.06	.60	24.34	1.4	4.1

1/ Analyses based onsamples with dockage, foreign material other than dockage, and glumes removed.
2/ Composite of all the glumes (hulls) removed from an equal weight of grain of each of the preceding sorghum samples.

Analyses by the Analytical and Physical Chemical Division, Northern Regional Research Laboratory.

Hygroscopicity

The sorghum grains, like all other cereal grains, lose moisture to the atmosphere, or gain moisture from it, until the moisture of the grain is in equilibrium with the humidity of the air. Data showing the moisture content of the grain of nine sorghums when in equilibrium with atmospheres of different relative humidities are presented in table 6.

In comparing the hygroscopicity of sorghum grain with that of other cereal grains it was found to be not greatly different. These comparative data are presented in table 7.

Waxy Sorghums

Waxy sorghums are clearly distinguished from the non-waxy varieties by the iodine test. When an aqueous solution of potassium iodide and iodine or of iodine alone is applied, the starch of the endosperm of waxy sorghum seeds stains red or reddish-brown, whereas that of non-waxy seeds gives a typical blue reaction. In this connection it is of interest to note that in the waxy seeds only the starch present in the endosperm stains red; starch present in the pericarp and the germ stains blue. Furthermore, the starch of stalks of waxy varieties stains blue. Split sorghum kernels stain with more difficulty than do split corn kernels, apparently because the sorghum endosperm is so closely packed with starch, etc. It is best when testing for waxiness, therefore, to stain a bit of starch scraped from the endosperm exposed in splitting.

In external appearance the waxy sorghum seeds resemble the other varieties except that they have a duller colored seed coat. When cut in two with a knife, however, the waxy seed may be distinguished from the non-waxy seed because the cut is more easily made and the break is accompanied by a muffled rather than a sharp sound. Their endosperm texture also is singularly different from that of non-waxy sorghums. It presents a waxy, or opaque, surface as contrasted to the hard, translucent corneous area surrounding the crumbly starch endosperm region of non-waxy varieties.

Sorghum varieties having waxy seeds have been grown in the United States since 1854, but have elicited very little interest until recently. They were introduced from China, where waxy sorghums, rice, barley, and millet have been grown for centuries. In that country they are known as "glutinous" sorghums, corn, etc., and are used as a delicacy during festivals.

The Bureau of Plant Industry, through its Division of Plant Exploration and Introduction, introduced some of these "glutinous" varieties some years ago but they did not prove to be as productive as our domestic grain sorghums. In 1921, however, a Bureau investigator determined that certain "glutinous" sorghums from the Orient had the same type of endosperm character as did the waxy corn also introduced from the Orient a few years previously. About 13 years later another Bureau investigator tested all

Table 6 - Equilibrium moisture content of nine varieties of sorghum grain exposed to atmospheres of different relative humidities at a temperature of 25° to 28° C.

Variety	Average moisture contents when atmospheric relative humidity percentage is -						
	13.8	31.0	43.0	59.0	76.0	87.0	100.0
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
White kafir	6.78	9.59	11.36	13.41	18.95	22.15	28.71
Red kafir	6.53	9.55	11.80	13.69	18.60	21.99	28.22
Yellow milo	6.54	9.57	11.74	13.48	17.95	22.00	27.34
Brown kaoliang	6.57	9.39	11.30	13.02	18.08	21.50	28.19
Darso	6.82	9.34	11.45	13.56	18.92	22.25	28.49
Feterita	6.69	9.64	11.37	13.41	17.82	22.39	27.03
Freed sorgo	6.45	9.22	11.19	13.06	17.52	21.97	28.30
Shallu	6.69	9.79	11.77	13.66	18.85	22.28	27.45
Schrock	6.79	9.45	11.45	13.53	19.04	22.13	28.60
Average	6.65	9.50	11.49	13.42	18.41	22.07	28.04

Source: Respiration of sorghum grains. By D. A. Coleman, et al. U. S. Dept. Agr. Tech. Bul. 100

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Table 7 - Equilibrium moisture contents of sorghum grain and other cereal grains exposed to atmospheres of different relative humidities at a temperature of 25° to 28° C.

Grain	Average moisture contents when atmospheric relative humidity percentage is -						
	15.0	30.0	45.0	60.0	75.0	90.0	100.0
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Sorghum grain	6.95	9.42	11.99	15.00	18.25	24.98	28.03
Corn	7.09	9.25	11.39	14.52	16.79	23.12	31.22
Wheat	7.03	9.34	10.99	13.81	17.30	24.82	34.38
Barley	6.45	9.24	11.16	13.74	16.88	24.17	36.65
Rye	7.49	9.58	11.72	13.94	17.41	25.92	36.51
Oats	6.03	8.76	10.60	13.40	16.05	22.65	31.71
Rice	7.27	9.92	12.00	14.38	16.86	22.15	30.85
Buckwheat	7.17	9.99	12.18	14.52	17.61	23.63	32.47

Source: Respiration of sorghum grains. By D. A. Coleman, et al. U. S. Dept. Agr. Tech. Bul. 100

the important American commercial varieties of sorghum and found that several of them had waxy seed.

The commercial waxy varieties of sorghums are Leoti and McLean sorgos, certain strains of Gooseneck sorgo, and a brown-seeded grain sorghum called Schrock or Sagrain. About 60 acres of a new waxy kafir and smaller areas of other waxy varieties were grown in 1942.

Possible special food or industrial uses for waxy sorghum have been considered for about 10 years, but commercial interest was lacking until the outbreak of war in the Pacific shut off imports of cassava root starches. However, about 1938 cooperative investigations at the Iowa Agricultural Experiment Station revealed that starch from waxy corn and waxy sorghum had properties similar to those of tapioca and sweetpotato starches. Information gained from further tests at the Northern Regional Research Laboratory, at the Nebraska Agricultural Experiment Station, and elsewhere, and the recent threatened shortage of tapioca starch, have stimulated the present interest in the commercial possibilities of waxy sorghum.

The present (1942) distribution of waxy sorghum production in the United States is not fully known. Most of the acreage consists of the Leoti variety grown for forage, largely in Nebraska and Kansas, and to some extent in other States. About 100,000 acres of Leoti were grown in 1942. The large acreage of Leoti has resulted from the purification, testing and distribution of the variety by the Department in cooperation with the Kansas and Nebraska Agricultural Experiment Stations. Schrock, known also as Sagrain, is grown for grain or forage chiefly in Texas, Oklahoma, Mississippi, Arkansas, and Kansas. McLean and Gooseneck sorgos are grown mostly for sirup on scattered areas in the South.

The agricultural division of the United States Patent Office grew a crop of waxy Chinese Amber sorgo on the Mall in Washington, D. C., in 1856, and distributed 275 bushels of seed to farmers in 1857. This was the first crop of any kind that was grown by a Federal agricultural agency.

Waxy sorghum may be processed for starch in a manner similar to that used for the commercial production of corn starch. Varieties containing a nucellar layer (see page 5) present more processing difficulties than those which have no nucellar layer, since the pigment always present in the nucellar layer tends to be adsorbed upon the starch. Modified milling and processing methods have, however, been developed which permit recovery of uncolored starch from pigmented sorghums. It is believed, therefore, that waxy sorghums offer a possibility for meeting immediate requirements for waxy starch during the present emergency. Waxy uncolored grain types without a nucellar layer are also being developed, from which starch can be extracted with even less modification of existing methods.

PRODUCTION AND VARIETY DISTRIBUTION OF SORGHUMS

Grain sorghum production is concentrated in the Great Plains area. Associated with the low and unevenly distributed rainfall of this region are relatively high summer temperatures, generally low atmospheric humidity, high wind velocity, and a large proportion of clear days, all of which contribute to a high rate of evaporation and a decrease in the effectiveness of rainfall. The structure of the sorghum plant, which enables it to withstand these unfavorable growing conditions, makes it particularly suited to this region. Its root system is composed of many fine roots capable of extracting most of the available moisture from the soil. Transpiration, or loss of plant moisture to the atmosphere, of the sorghum plant is relatively low owing to its comparatively small leaf area (about 1/3 less than that of corn), to a waxy bloom on the leaves and sheaths, and to an ability of the leaves to roll up when dry conditions prevail. The sorghum plant also has the ability to suspend growth during severe periods of drouth and to resume growth when conditions permit. In addition, sorghum grain is, after its formation on the plant, less susceptible to damage by hot weather than is the case with corn.

In the southern part of the Great Plains, rainfall is the limiting growth factor, while in the northern Great Plains, length of growing season as determined by temperature is the limiting factor in grain sorghum production. The optimum temperature for sorghum growth is estimated at about 92° F. with only indifferent growth being made at temperatures lower than 60° F. Altitude with certain modifications is also a production-limiting factor, the upper limit of successful sorghum production varies with the latitude from about 4,000 feet in Montana to 7,000 feet in southern New Mexico.

The Great Plains area leads in sorghum production and the States forming its eastern boundary rank practically in descending order from south to north, in both grain sorghum and sorgo acreage, as follows: Texas, Kansas, Oklahoma, Nebraska, and South Dakota. (See table 8.) Colorado and New Mexico, on the western boundary of the Great Plains, are next in importance. In all States where sorghums are grown, except California and Arizona, the major portion of the acreage is for forage. Nebraska and South Dakota assumed importance as grain sorghum producing States only within the past decade. This was due to the failure, because of drouth in this area, of corn and the small grain crops in almost every year of the 1930-39 decade. Coincident with this, earlier-maturing varieties of sorghum adapted to the relatively short growing season of these States have been developed and their production encouraged. The use of sorghum for silage increased sharply between 1930 and 1940. In 1930, approximately 106,000 acres of sorghum were utilized for silage, in 1940 about 1,238,000 acres were utilized for this purpose. In figure 4 is shown the distribution of the acreage of sorghum harvested for grain in 1939.

Sorghums can also be grown successfully in the Corn Belt and in the Southeastern States. Other crops, however, are relatively more profitable in

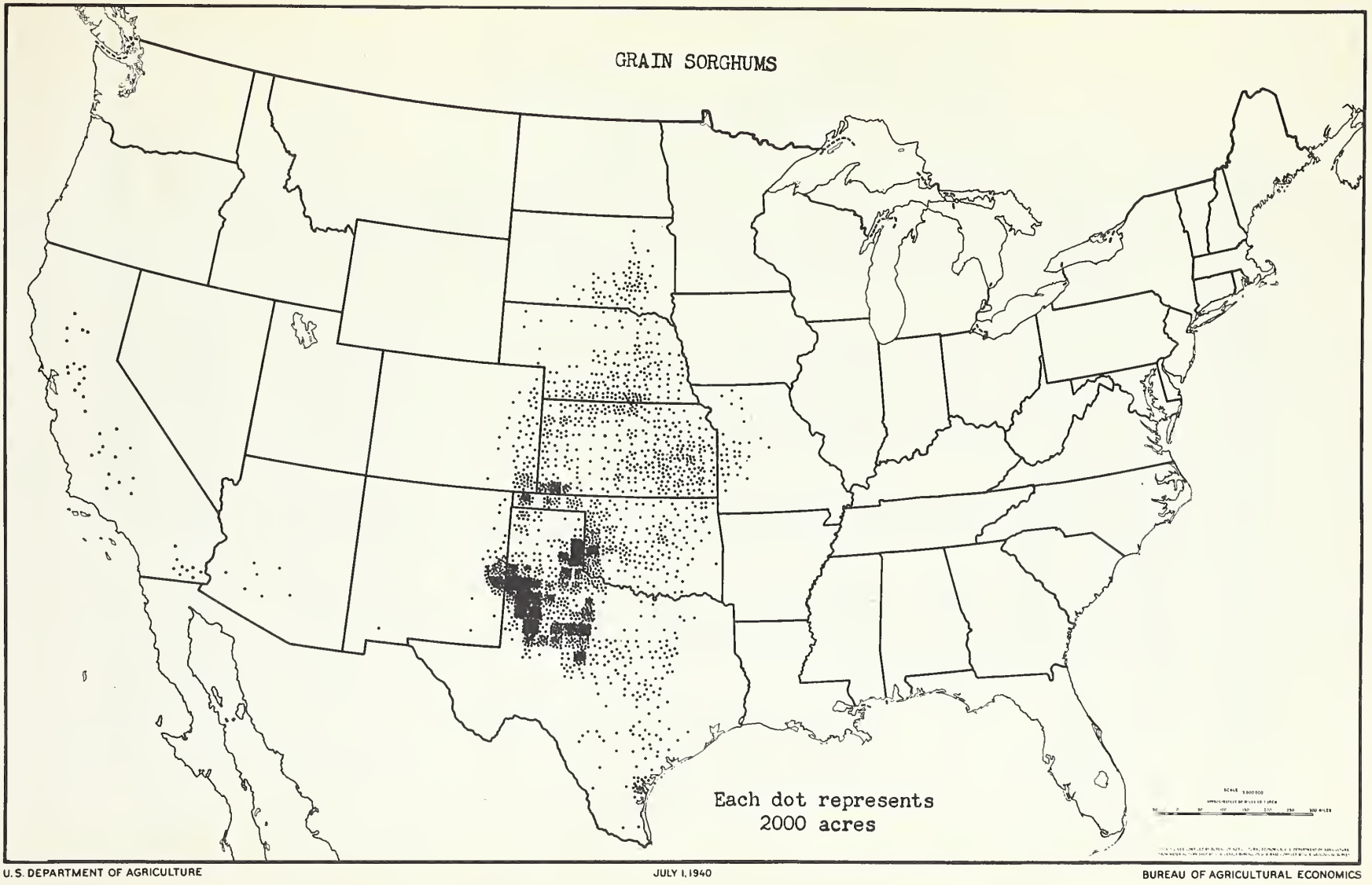

Figure 4. - Grain sorghums for grain harvested acreage, 1939

Table 8 - Harvested acreage of sorghums for grain and for forage in the principal producing States and total for the United States, crops of 1940 and 1941, and average for 1930-39.

State	Acreage harvested for --								
	Grain 1/			Forage 2/			Total		
	Average 1930-39	1940	1941	Average 1930-39	1940	1941	Average 1930-39	1940	1941
	Thousand acres			Thousand acres			Thousand acres		
Missouri	51	70	49	239	256	235	290	326	284
South Dakota	--	172	250	318	990	962	318	1162	1212
Nebraska	63	464	226	460	1315	1000	523	1779	1226
Kansas	796	1697	1275	1241	1969	1464	2037	3666	2739
Arkansas	12	13	8	118	105	82	130	118	90
Oklahoma	806	900	667	977	1248	1191	1783	2148	1858
Texas	1957	2355	2839	2888	4357	3882	4845	6712	6721
Colorado	80	202	170	348	673	742	428	875	912
New Mexico	152	145	241	222	291	236	374	436	477
Arizona	24	21	46	6	6	6	30	27	52
California	108	135	204	--	--	--	108	135	204
Illinois	--	--	--	8	10	7	8	10	7
Iowa	--	--	--	41	73	49	41	73	49
North Dakota	--	--	--	44	187	153	44	187	153
Virginia	--	--	--	4	4	3	4	4	3
North Carolina	--	--	--	22	14	14	22	14	14
South Carolina	--	--	--	20	15	12	20	15	12
Georgia	--	--	--	41	39	35	41	39	35
Kentucky	--	--	--	47	30	31	47	30	31
Tennessee	--	--	--	58	39	39	58	39	39
Alabama	--	--	--	33	28	32	33	28	32
Mississippi	--	--	--	29	28	22	29	28	22
Total	4049	6174	5975	7164	11677	10197	11213	17851	16172
United States	4083	6183	5982	7208	11761	10276	11291	17944	16258

1/ Consists of all sorghums (grain sorghums and sorgos) threshed, combined, or headed for grain.

2/ Consists of all sorghums (grain sorghums and sorgos) cut for silage, hay, or fodder (cut and fed without removing the heads), or grazed.

Source: Bureau of Agricultural Economics, U. S. Dept. Agr.

these sections; consequently the sorghums are grown to only a limited extent. The sorghums grown in these areas are used almost entirely for forage except for the 200,000 to 300,000 acres grown annually for sirup, chiefly in the Deep South. Sirup production from sorghum amounts to around 12 million gallons annually.

Table 9 shows, by States, the United States acreage, yield, and production of grain sorghums. Harvested acreage averaged approximately 4 million acres for the years 1930-39 and increased to 6.0 million acres in 1941. Production likewise increased from an average of 52.7 million bushels for the 1930-39 period to 111.8 million bushels in 1941. Texas, the leading state, harvested over 2.8 million acres of grain sorghums in 1941; Kansas harvested 1.3 million acres; Oklahoma harvested 667,000 acres; each of the other States harvested less than one-quarter million acres of sorghums for grain.

Data regarding the distribution of sorghum acreages by varieties have not been collected on a nation-wide basis since 1925, when a survey dealing with 1924 acreages was conducted by the United States Department of Agriculture in the sections of the United States known to produce an appreciable acreage. In this survey no account was taken as to how the crops were used, whether for grain or for forage. The results of the survey are shown in table 10 for grain sorghum varieties, and in table 11 for sorgo varieties. As will be noted from table 10, kafirs and milos were by far the most widely distributed grain sorghum varieties and were grown on the largest acreages. This continues to be the case today (1942). However, changes in the acreage of some of the less important varieties have undoubtedly occurred. For example, Schrock, a waxy variety, was grown on a very limited scale in 1924, but it is reported that in recent years a considerable acreage of this variety has been grown in South Texas. Also several new varieties have been developed which have become commercially important.

Among the sorgos, Sumac, Black Amber, and Orange accounted for over two-thirds of the total United States acreage. (See table 11.) The first two named were grown in all of the principal producing states. The waxy varieties, Gooseneck, Leoti, and McLean, were grown on a very small acreage in 1924. As previously mentioned, there has been a considerable increase since that time in Leoti acreage, especially in Nebraska where approximately 100,000 acres were grown in 1942 3/. No expansion in Gooseneck and McLean acreages has been reported.

DISPOSITION OF SORGHUM GRAIN

The farm disposition of sorghum grain for the years 1930 to 1941 is shown in table 12. For these 12 years, the quantity of grain sold off farm of production averaged 15.3 percent of production, or a little over 14 million

3/ According to a cooperative survey conducted in that state by the Nebraska Agr. Expt. Sta. and the Office of the State-Federal Agricultural Statistician.

Table 9 - Acreage harvested, yield, and production of grain sorghums 1/ harvested for grain in the principal producing states, crops of 1940 and 1941, average for 1930-39.

State	Acreage harvested			Yield per acre			Production		
	Average 1930-39	1940	1941	Average 1930-39	1940	1941	Average 1930-39	1940	1941
	Thousand acres			Bushels			Thousand bushels		
Missouri	51	70	49	13.4	20.9	18.9	755	1464	926
South Dakota	--	172	250	---	9.4	10.4	--	1622	2610
Nebraska	63	464	226	11.2	10.4	15.7	677	4835	3553
Kansas	795	1697	1275	9.8	12.8	17.2	8656	21796	21885
Arkansas	12	13	8	11.4	17.8	15.8	142	232	126
Oklahoma	806	900	667	9.2	11.5	12.0	7652	10314	7982
Texas	1957	2355	2839	13.8	14.4	20.4	27678	34008	57976
Colorado	80	202	170	8.5	9.4	13.2	693	1892	2237
New Mexico	152	145	241	11.7	9.5	22.9	1870	1375	5522
Arizona	24	21	46	29.0	26.5	32.0	698	556	1472
California	108	135	204	32.6	36.0	36.0	3557	4860	7344
Total	4049	6174	5975	12.9	13.4	18.7	52378	82954	111633
United States	4083	6183	5982	12.9	13.5	18.7	52747	83164	111784

1/ Intended to include only grain sorghum varieties, but may include some production of sorgo varieties such as Atlas because of the fact that in some areas farmers report them as grain sorghums.

Source: Bureau of Agricultural Economics. U. S. Dept. Agr.

Table 10 - Estimated acreages of grain sorghum [1/] varieties grown in the principal sorghum-producing States in 1924.

State	Kafirs	Milos	Feteritas	Hegari	Darso	Freed	Durras	Schrock	Others [2/]	Totals
	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Acres
Alabama	480	208	2	--	--	--	--	--	90	780
Arizona	471	4397	362	6675	4	--	29	--	260	12198
Arkansas	2733	550	500	123	499	--	--	318	274	4997
California	381	27187	487	581	--	--	6475	--	46	35157
Colorado	39327	39947	5408	3298	--	7981	19	--	612	96592
Georgia	270	68	86	--	--	--	--	--	498	922
Kansas	932451	167900	98050	22992	2107	10516	2784	6296	3325	1246421
Kentucky	292	53	--	--	--	--	--	--	9	354
Missippi	28	--	77	--	--	--	--	1049	230	1384
Missouri	46906	2984	3844	65	--	--	--	21	693	54513
Nebraska	15987	639	2011	--	--	111	--	--	21	18769
New Mexico	73565	126552	5397	15933	113	--	945	--	383	222888
North Carolina	--	36	--	--	--	--	--	--	--	36
Oklahoma	541975	413368	91262	26410	46010	--	294	1819	16577	1137715
South Carolina	--	--	--	--	--	--	--	--	--	--
Tennessee	271	47	40	--	--	--	--	--	112	470
Texas	369546	992103	128256	134715	30345	181	1761	423	9509	1666839
Totals	2024683	1776039	335782	210792	79078	18789	12307	9926	32639	4500035

1/ For all purposes--grain and forage.

2/ Includes Fargo, Bishop, Shallu, and others.

Source: Identification, history, and distribution of common sorghum varieties. By H. N. Vinall, et al. U. S. Dept. Agr. Tech. Bul. 506, July 1936.

Table 11 - Estimated acreages of sorgo [1/] varieties grown in the principal sorghum-producing States in 1924.

State	Sumac	Black Amber	Orange	Honey	Red Amber	Sourless	Gooseneck	Leoti	McLean	Others [2/]	Field run	Total
Ala.	7948	7802	11223	9649	546	766	554	--	--	8403	--	46891
Ariz.	306	703	--	628	247	--	--	--	--	547	--	2431
Ark.	2192	10175	30367	29194	2901	935	791	--	693	39745	2210	119203
Calif.	58	269	--	161	--	--	--	--	--	184	--	672
Colo.	20373	92579	19654	10	15458	2464	--	--	--	4239	14918	169695
Ga.	2967	10114	14423	8351	662	587	252	--	--	9526	--	46882
Kan.	164058	201019	88470	2565	67007	63006	--	4136	--	67653	112456	770370
Ky.	16488	4757	13697	2025	576	821	64	--	19	16910	5787	61144
Miss.	3686	5718	6959	6395	662	282	759	--	--	7765	106	32332
Mo.	1937	45178	46629	12052	10565	1274	375	--	--	28409	9073	155492
Neb.	621	98602	23493	--	20385	313	--	--	--	2676	7285	153375
N.Mex.	24414	14707	66	13368	6645	762	--	--	--	623	6105	66690
N.Car.	333	1668	3154	1746	427	--	137	--	--	7380	36	14881
Okla.	186024	65281	62406	29590	15849	45897	496	--	--	17274	60086	482903
S.Car.	229	674	1213	378	9	14	50	--	--	761	--	3328
Tenn.	25931	4533	20953	15586	2111	726	753	--	--	18228	1637	90458
Tex.	603331	80668	49829	41076	16235	1026	403	--	--	22209	90421	905198
Totals	1060896	644447	392536	172774	160285	118873	4634	4136	712	252532	310120	3121945

1/ For all purposes--grain and forage.

2/ Includes Colman, Kansas Orange, Sapling, Planter, Folger, White African and others.

Source: Identification, history, and distribution of common sorghum varieties. By H. N. Vinall, et al. U. S. Dept. Agr. Tech. Bul. 506. July 1936.

Table 12 - Production of grain sorghums 1/, farm disposition, and exports, United States, 1930-41.

Year	Production for all purposes 2/	Farm disposition			Exports 5/
		Feed 3/ and seed	Sold 4/		
			Quantity	Proportion	
	1000 bu.	1000 bu.	1000 bu.	Percent	1000 bu.
1930	62570	55721	6849	10.9	
1931	113649	96894	16755	14.7	
1932	109745	97110	12635	11.5	
1933	82685	71371	11314	13.7	
1934	40225	37949	2276	5.7	
1935	98495	86258	12237	12.4	6/ 1857
1936	55079	48698	6381	11.6	2
1937	97679	79354	18325	18.8	88
1938	99136	83553	15583	15.7	675
1939	83264	71446	11818	14.2	2
1940	127894	104039	23855	18.7	1
1941 7/	153968	119939	34029	22.1	8/
Average	93699	79361	14338	15.3	

1/ For all purposes.

2/ Includes grain equivalent on forage acreage.

3/ Relates to quantities used on farms where produced. Additional quantities of purchased grain sorghums are so utilized.

4/ Includes grain sorghums sold to other farmers for livestock feed, as well as grain sorghums sold for commercial utilization.

5/ Included in grain sorghums sold.

6/ 1931-35 average.

7/ Preliminary.

8/ Not available.

Sources: Agricultural Marketing Administration, U. S. Dept. Agr.
Bureau of the Census, U. S. Depart. Comm.

bushels.

Texas accounts for the largest amount of grain sold off farm of production, whereas California accounts for the largest percentage sold. The latter fact is probably due to the wide-spread use of sorghum grain for feed by the large commercial poultry raisers in California.

Very little sorghum grain enters into international trade. The 1931-35 annual average exports (see table 12) amounted to 1.9 million bushels. Since 1935, exports have been practically non-existent, totaling only one thousand bushels in 1940.

The ten leading grain sorghum markets and the quantities of sorghum grain received by rail at these points in 1941 follow:

Market	Quantity of sorghum grain received by rail, 1941 calendar year
	Bushels
Kansas City, Mo. and Kansas	2,893,800
Fort Worth, Texas	2,625,000
Lubbock, Texas	1,563,800
Amarillo, Texas	1,450,400
Hutchinson, Kansas	1,115,800
Los Angeles, California	1,040,200
Dallas, Texas	749,000
Dodge City, Kansas	365,400
Sherman, Texas	274,400
Houston, Texas	222,600

(Data furnished by the Grain Products Branch, Food Distribution Administration, USDA)

These figures do not include receipts by truck.

Table 13 shows the average farm prices of grain sorghums in the principal grain sorghum producing states as compared with farm prices of corn.

Commercial Grades

For marketing purposes grain sorghums are divided by the official Grain Standards of the United States into five classes: Class I, White Grain Sorghums; Class II, Yellow Grain Sorghums; Class III, Red Grain Sorghums; Class IV, Brown Grain Sorghums; and Class V, Mixed Grain Sorghums. These classes are broken down into subclasses as follows: Class I--White Kafir, White Durra, and White Grain Sorghums; Class II--Yellow Milo and Yellow Grain Sorghums; and Class III--Red Kafir and Red Grain Sorghums. Under each class or subclass, as the case may be, there are five grades, e.g., No.1, No. 2, No. 3, No. 4 and Sample grade, and, in addition, special grade designations are applied for certain conditions. The special grade

Table 13 - Average prices per bushel received by farmers for grain sorghums in the principal grain sorghum-producing States as compared to corn. 1934-1940.

State	1934		1935		1936		1937		1938		1939		1940 1/	
	Grain sorghums	Corn	Grain sorghums	Corn	Grain sorghums	Corn	Grain sorghums	Corn 2/	Grain sorghums	Corn 2/	Grain sorghums	Corn 2/	Grain sorghums	Corn
	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents	Cents
Missouri	146	95	85	72	106	116	65	51	57	49	64	55	62	59
South Dakota	3/	84	3/	50	3/	108	60	45	41	51	45	51	44	56
Nebraska	158	87	67	61	106	116	61	51	36	50	48	56	42	58
Kansas	108	97	68	73	104	120	46	56	35	50	55	58	39	60
Arkansas	3/	96	75	82	98	100	52	60	64	53	70	66	64	59
Oklahoma	94	99	65	70	104	106	53	55	44	49	63	60	49	54
Texas	97	83	50	53	92	91	45	65	37	44	56	55	52	52
Colorado	130	97	66	66	96	110	47	63	34	46	56	62	40	60
New Mexico	94	106	52	72	91	111	46	75	38	62	52	75	49	62
Arizona	82	106	62	83	87	112	59	86	48	79	71	84	62	84
California	78	99	59	79	88	107	66	75	53	71	69	81	59	82
Average 4/ 11 States	97.8	90.1	56.1	63.0	94.9	104.6	48.8	54.7	39.2	49.1	56.4	56.5	48.0	57.1
United States 4/	97.8	81.6	56.1	65.5	94.9	104.5	48.8	52.0	39.2	50.0	56.4	56.7	48.0	62.4

1/ Preliminary.
2/ Includes an allowance for unredeemed loans at average loan value.
3/ Not available.
4/ Weighted by production.

Source: Agricultural Statistics, U. S. Dept. Agr.

designations are: "Bright", "Discolored", "Weevily", and "Smutty". The numerical grades are based on minimum requirements for test weight and maximum percentage limits for moisture, damaged kernels, nongrain sorghums and total cracked kernels, foreign material and other grains. The standards also provide for the grading of this grain on a "Dockage" basis.

Relative Value as a Farm Crop

Of the so-called minor grains--sorghum, rice, rye, buckwheat, and millet--grain sorghums are the most important in the United States from the standpoint of acreage, production, and farm value. In the semiarid regions of the United States they largely take the place of corn as a livestock feed, and are chiefly utilized as such on farms where grown. Table 14 shows the average farm value and cash income from grain sorghums for all purposes in comparison with various other grains produced in the United States for the period 1935-39 and the years 1940 and 1941. The farm value of grain sorghums averaged 48 million dollars for the period 1935-39 and was 84 million dollars in 1941. The cash farm income from grain sorghums averaged 7 million dollars for the 1935-39 period and was 14 million dollars in 1941.

Table 14 - Farm value and cash farm income, various grains, average 1935-39, and the years 1940 and 1941.

Crops	Farm value			Cash farm income		
	Average 1935-39	1940	1941 1/	Average 1935-39	1940 1/	1941 1/
	$1000	$1000	$1000	$1000	$1000	$1000
Grain sorghums 2/	48200	61897	83710	7261	8857	14475
Rice	35864	44208	72476	29685	39902	52855
Rye	22755	17094	24866	12739	8182	13415
Buckwheat	4329	3495	4103	1804	1277	1220
Corn, all	1435758	1520047	2012651	262923	387932	351271
Wheat	609845	554168	894783	451262	427541	702039
Oats	312317	377171	484070	51430	57296	84951
Barley	109238	122953	184244	40791	41270	56027

1/ Preliminary.
2/ For all purposes.

Harvesting Grain Sorghums

One of the principal disadvantages of growing grain sorghums is the difficulty and cost of harvesting. Some varieties do not readily lend themselves to harvesting mechanically, and harvesting by hand is too laborious to be practicable for large acreages. Much work has been done to develop

varieties adaptable to machine harvesting.

Grain sorghums may be harvested by: (a) heading by hand or with a grain header, (b) cutting with a row binder or grain binder, (c) combining, and (d) various modifications of these methods largely improvised by individual farmers. For small acreages, which do not warrent the owning of harvesting machinery, harvesting by cutting off the heads by hand is usually practiced.

To be readily harvested by combining, grain sorghums must be rather short and regular in height, the stalks should be resistant to lodging, and the heads should be erect and should ripen as uniformly as possible. Immature grain contains considerable moisture when cut and immediately threshed or when combined, and frequently goes out of condition during storage if the moisture content is too high. If a considerable proportion of the kernels is cracked in the threshing or combining process this also increases the danger of spoiling in the bin.

USES

Of the 94 million bushels average yearly production of grain sorghums from 1930 to 1941, 85 percent was consumed for seed and feed on the farm where produced. The remaining 15 percent was sold. (See table 12.) Of this latter percentage an undeterminable portion was purchased by farmers for feed in the vicinity of its production so that the quantity actually entering commercial channels was appreciably smaller than 15 percent of production.

Seed

The quantity of grain sorghum used for seed is not capable of exact estimation owing to the diversity in the manner of planting, varietal differences in size of seed, and the great variation in growing conditions. In the principal grain sorghums producing region, rate of planting ranges from 2 to 8 pounds of seed per acre. An average figure would probably approximate 5 pounds per acre. Applying this rate to the 1930-39 average grain sorghum planted acreage of 8.7 million acres for all purposes, gives an annual estimated requirement for seed of about 775,000 bushels, or approximately 1-1/2 percent of grain sorghum production for grain.

Feed

Grain sorghums are used almost entirely as feed for livestock, and are fed principally on the farm where grown or in the immediate vicinity. This crop is to the grain sorghum producing region what corn is to the Corn Belt.

As was previously pointed out, grain sorghums are generally slightly higher in protein content but have a lower fat content than corn. According to

Morrison 4/, they are nearly as deficient in calcium as is corn, and, like corn, are lower in phosphorous than wheat, oats, or barley; all varieties are apparently low in vitamin A, and also deficient in vitamin D. The composition of the grain, green forage, dried forage, and silage of various sorghums is compared to that of corn in table 15.

In general, grain sorghums are considered to have 90 to 95 percent of the feeding value of corn. Their value for feeding dairy cows and sheep is practically the same, pound for pound, as corn; for fattening cattle or swine, their value is somewhat lower. When properly supplemented with feeds rich in protein, calcium, and vitamins A and D, the grain sorghums are excellent for all classes of livestock.

All the grain sorghums are palatable to livestock except the brown-seeded varieties which contain tannin, or a substance similar to tannin, that makes them bitter to the taste. It is recommended that the grain be ground when fed to all classes of livestock except poultry and sheep; otherwise the small hard seeds are apt to pass through the animal undigested.

Results of experimental trials for growing fattening hogs by the Nebraska Experiment Station, Lincoln, Nebraska, are shown in table 16.

Grain sorghums, especially kafir and milo, are excellently adapted and widely used for poultry feed. They are small enough in size to be readily fed without cracking or crushing. They are also used extensively in the manufacture of mixed commercial poultry feeds.

4/ F. B. Morrison. Feeds and Feeding, 20th Edition.

Table 15 - Composition of grain, green forage, dried forage, and silage of specified sorghums with comparisons.

Feedstuff	Moisture	Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Calcium	Phosphorus
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Grains:								
Corn, shelled	12.9	1.3	9.3	4.3	1.9	70.3	0.01	0.26
Corn chop	11.3	1.4	9.8	4.1	2.1	71.3	.01	.26
Feterita	9.1	1.7	14.2	2.9	1.4	70.7	1/	1/
Kafir	11.9	1.7	11.1	3.0	2.3	70.0	.01	.25
Kafir head chops	10.4	3.9	10.9	2.5	6.0	66.3	.09	.20
Milo	9.3	1.6	12.5	3.2	1.5	71.9	1/	1/
Milo head chops	10.4	4.3	10.7	2.6	7.1	64.9	1/	1/
Sorgo	12.8	2.1	9.1	3.6	2.6	69.8	1/	1/
Green Forages:								
Corn fodder:								
Dent, immature	79.0	1.2	1.7	.5	5.6	12.0	1/	1/
Dent, mature	73.4	1.5	2.0	.9	6.7	15.5	1/	1/
Kafir	73.0	2.0	2.3	.7	6.9	15.1	1/	1/
Sorgo	77.3	1.3	1.5	1.0	6.2	12.7	1/	1/
Sweet corn	79.1	1.3	1.9	.5	4.4	12.8	1/	1/
Dried Forages:								
Corn fodder	11.8	5.8	7.4	2.4	23.0	49.6	1/	1/
Cornstalks	11.7	4.6	4.8	1.8	32.7	44.4	1/	1/
Corn stover	10.7	6.1	5.7	1.5	30.3	45.7	.45	.10
Feterita fodder	13.3	6.4	8.7	1.9	21.5	48.2	.27	.19
Hegari fodder	13.5	8.2	6.2	1.7	16.7	53.7	.17	.18
Hegari stover	15.1	9.7	4.5	1.9	26.6	42.2	.38	.09
Kafir fodder	9.1	7.8	6.6	2.1	28.4	46.0	.31	.05
Kafir stover	12.6	9.0	5.8	1.7	27.5	43.4	1/	1/
Sorgo fodder	11.6	6.0	5.3	2.4	26.0	48.7	.27	.15
Sorgo hay	5.8	9.5	9.5	1.9	26.8	46.5	.31	.09
Johnson grass hay	7.2	7.2	8.1	2.8	30.4	44.3	.55	.40
Silages:								
Corn, immature	79.1	1.4	1.7	.8	6.0	11.0	1/	1/
Corn, mature	70.9	1.4	2.4	.9	6.9	17.5	1/	1/
Corn stover	80.7	1.8	1.8	.6	5.6	9.5	1/	1/
Hegari	66.3	3.4	2.3	.8	6.7	20.5	1/	1/
Sorgo	74.7	1.4	1.6	1.0	6.9	14.4	.09	.04

1/ Data are lacking.

Source: Composition of the principal feedstuffs used for livestock. By N. R. Ellis, et al. Yearbook of Agriculture, 1939. U.S. Dept. Agr.

For comparison with other feedstuffs see "Brewers' and Distillers' By-products and Yeasts in Livestock Feeding" A.H.D. 58, Bur. Animal Industry, U. S. Dept. Agr., 1942.

Table 16 - Relative feeding value per 100 pounds of milo or kafir and other feeds, as compared to corn for growing fattening hogs.

When price of 100 lbs. of corn is -	Relative feeding value of 100 lbs. of --				
	Milo or kafir	Cane seed	Wheat shorts	Hominy feed	Cane molasses
Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
.75	.68	.56	.68	.71	.60
1.00	.90	.75	.85	.95	.30
1.25	1.13	.94	1.06	1.19	1.00
1.50	1.31	1.13	1.28	1.43	1.20
1.75	1.58	1.31	1.49	1.66	1.40
2.00	1.80	1.50	1.70	1.90	1.60
2.25	2.03	1.69	1.91	2.14	1.80

Source: Extension Circular 216. Nebraska Agr. Expt. Sta.

Table 17 shows the digestible protein and total digestible nutrient content of grain, green forage, dried forage, and silage of specified sorghums as compared with corn.

Food

The early white settlers in the semiarid regions of the United States depended heavily on grain sorghums as an important source of food, especially in years of severe drouth when corn and wheat failed. Since then, however, grain sorghums have been used very little in the American diet.

Nevertheless, flours may be made very easily from grain sorghums and their use adds pleasing variety to bread and other cereal products. Bavousett and Kleppe (see selected references, page 33), of the Home Economics Department of Texas Technological College, report that flours made from hegari, kafir, and Yellow milo have been used in making various quick breads and yeast breads. They state that standard recipes for muffins, baking-powder bread, griddle cakes, waffles, or gingerbread may be modified by substituting flour made from hegari, kafir, or milo for two-thirds of the wheat flour called for. More desirable results are obtained for yeast breads and biscuits by using half hegari, kafir, or milo flour and half wheat flour.

To make flour from grain sorghums, good quality threshed grain, well-matured and free of mold, is desired. The grain should be freed of chaff and dust by passing it through a fanning mill or other seed-cleaning machine. For grinding, a simple hand mill, a buhr mill, or a hammer mill, such as is commonly used for grinding feeds on the farm, may be used. When a hammer mill is used, a one-sixteenth inch screen gives a flour of desirable fineness. If a hand mill is used, the flour should be sifted several times

Table 17 - The digestible protein and total digestible nutrient content of grain, green forage, dried forage, and silage of specified sorghums with comparisons, as determined for cattle, sheep, and swine.

Feedstuff	Digestible protein for -			Total digestible nutrients for -		
	Cattle	Sheep	Swine	Cattle	Sheep	Swine
	Percent	Percent	Percent	Percent	Percent	Percent
Grains						
Corn chop	--	--	7.7	--	--	82.0
Feterita	--	10.9	--	--	81.0	--
Kafir	9.0	7.1	8.5	79.7	70.9	81.4
Kafir head chops	--	6.9	--	--	67.8	--
Milo	8.3	9.5	7.6	75.9	85.6	72.7
Milo head chops	--	8.1	--	--	76.0	--
Sorgo	4.5	4.7	5.5	71.8	64.6	1/ 69.3
Green Forages:						
Corn fodder, dent	1.1	1.1	--	11.2	14.4	--
Dried Forages:						
Corn fodder	3.4	--	--	54.4	--	--
Corn stover	2.5	2.1	--	53.4	49.8	--
Kafir fodder	2.5	3.4	--	52.8	54.3	--
Kafir stover	2.3	2.4	--	50.2	45.9	--
Sorgo fodder	3.3	1.7	--	60.2	49.4	--
Johnson grass hay	--	3.6	--	--	53.2	--
Silages:						
Corn	1.0	1.1	--	17.5	17.4	--
Corn stover	.7	.9	--	10.4	10.1	--
Sorgo	--	.4	--	--	16.1	--

1/ Crude fiber not included in calculation.

Source: Composition of the principal feedstuffs used for livestock. By N. R. Ellis, et al. Yearbook of Agriculture, 1939. U. S. Dept. Agr.

through a fine sieve after grinding. The "grits" may be either reground or cooked for breakfast cereal in the same manner as hominy grits.

Industrial Uses

Sorghum grain to date has been utilized very little in industry. The relatively small quantity produced and its utilization almost entirely as feed has left no great surplus clamoring for industrial outlets. However, owing to the continued development of better-yielding and wider-adapted varieties and of varieties readily harvested by combining, sorghum grain production may expand to proportions which will require industrial outlets to utilize them fully. The development of waxy varieties with their expected specific industrial applications may result in the industrial utilization of a considerable quantity of sorghum grain.

Starch

The commercial use of sorghum grain in the manufacture of waxy starch was begun in 1942. Experiments to test the practicability of using sorghum grain in the manufacture of starch are being conducted at the Kansas and Nebraska Agricultural Experiment Stations, and by the Starch and Dextrose Division of the Northern Regional Research Laboratory in connection with its study of starch from waxy corn. The properties of the starch and the processing technique are being studied by industrial concerns as well as by the above mentioned research laboratories and new uses and commercial applications are being sought.

The extraction of pure-white starch from varieties having a nucellar layer (source of its characteristic color) presents some difficulties. The pigment of the nucellar layer dissolves in the processing liquors and is adsorbed upon the starch granules. Modified milling and processing methods have, however, been developed by which white starch can be obtained from sorghum varieties containing the pigmented nucellar layer. Waxy varieties have been bred in which this layer is not present, and which, therefore, can be processed by methods more closely resembling those now used for cornstarch production.

Alcohol

Alcohol may be derived from the starch contained in sorghum grain by saccharification and fermentation. Although its commercial yield of alcohol compares somewhat favorably with that of other grains (see table 18), the quantity which has been utilized as an alcohol raw material is so small that no data regarding its use as such are reported. It appears likely that, while ample supplies of corn and other grains commonly used for alcohol production are available, distillers will not use sorghum grain to any appreciable extent. Price relationships would have to favor sorghum grain very considerably to persuade distillers to use it in place of those grains to which they are accustomed. However, at least one alcohol plant has been using this grain extensively.

Table 18 - Quantity of alcohol obtainable from grain sorghums with comparisons.

Raw material	Weight per bushel	Average fermentable content	Probable commercial yield of 99.5-percent alcohol	
			Average per bushel	Average per ton
	Pounds	Percent	Gallons	Gallons
Grain sorghums	56	54.5	2.22	79.5
Corn	56	57.8	2.35	84.0
Barley	48	54.3	1.9	79.2
Wheat	60	58.6	2.57	85.0
Malt	34	60.6	1.5	90.0
Oats	32	43.6	1.02	63.6
Rice	45	54.6	1.79	79.5
Rye	56	54.0	2.20	78.8
Buckwheat	48	57.2	2.00	83.3

Source: Motor Fuels from farm products. P. B. Jacobs and H. P. Newton. Misc. Pub. No. 327, U. S. Dept. Agr.

GRAIN SORGHUMS UTILIZATION RESEARCH

Present and suggested researches on grain sorghums include determination of the influence of varietal, cultural, and environmental factors on the physical and chemical properties and utility of the grain sorghums proteins, oil, and carbohydrates; studies on their mineral and vitamin content; studies on the utility of their carbohydrates, proteins, and oils for the manufacture of starch, alcohol, adhesives, plastics, paints, etc., and investigations on the malting properties, and the diastatic and proteolytic enzymes of grain sorghums to determine their adaptability for use in the fermentation processes and for other technological purposes.

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